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*PHYSICAL HISTORY OF THE ROCKY MOUNTAIN REGION IN CANADA.**

IT will now be endeavored to briefly review the orographic changes and the conditions of deposition of which the geological column gives evidence—in other words, to touch in outline the main facts of the physical history of the Rocky Mountain region of Canada.

Regarding the Archean, it need only be said that here, as in most parts of the world, we find, beneath any rocks that can be assigned to the Cambrian in the most extended sense of that term, and apparently separated from these rocks, by a great break and unconformity, a crystalline series or 'fundamental complex' composed of plutonic rocks with highly metamorphosed and vanishing sedimentary rocks in seemingly inextricable association. The similarity of this basal series in different parts of the world is so great as apparently to imply world-wide and approximately contemporaneous conditions, of a kind perhaps differing from any that can have occurred at later periods. The region here described is not, however, an ideal one for the study of these Archean rocks, because of the extreme metamorphism by which much newer formations

* Concluding section of the address of the President of the Geological Society of America, the late Dr. George M. Dawson, read before the Society on December 29, 1900.

have often been affected in it; nor has any series yet been defined that appears here to bridge the gap between the Archean and the strata that may with propriety be attached to the Cambrian.

In the earlier series of deposits assigned to the Cambrian, we discover evidence of a more or less continuous land area occupying the position of the Gold ranges and their northern representatives, and aligned in a generally northwesterly direction. The Archean rocks were here undergoing denudation, and it is along this axis that they are still chiefly exposed, for although they may at more than one time have been entirely buried beneath accumulating strata, they have been brought to the surface again by succeeding uplifts and renewed denudation. We find here, in effect, an Archean axis or geanticline that constitutes, I believe, the key to the structure of this entire region of the Cordillera. To the east of it lies the Laramide geosyncline (with the conception of which Dana has familiarized us) on the west another and wider geosyncline, to which more detailed allusion will be made later.

Conglomerates in the Bow River series indicate sea margins on the east side of this old land, but these are not a marked feature in the Nisconlith, or corresponding series on its western side. Fossils have so far been discovered only in the upper part of the Bow River series, but the prevalence of carbonaceous and calcareous material (particularly in the Nisconlith) appears to indicate the abundant presence of organisms of some kind at this time.

Although no evidence has been found of any great physical break, the conditions indicated by the upper half of the Cambrian are very different from those of the lower. Volcanic materials, due to local eruptions, were accumulated in great mass in the region bordering on the Archean axis to the west, while on the east materials of this kind appear to be mingled with the preponderant shore deposits of that side of the Archean land, and to enter sparingly into the composition of the generally calcareous sediments lying still farther eastward. Where these sediments now appear in the eastern part of the Laramide range they are chiefly limestone, indicating marine deposition at a considerable distance from any land.

The history of the Ordovician, Silurian and Devonian times is very imperfectly known. Marine conditions still prevailed to the eastward of the Archean axis and were probably continuous there, but our knowledge of the region to the west, while as yet almost entirely negative in its character, is not sufficiently complete to enable us to assume the existence of any extensive land area in that quarter. In the Devonian the sea is known to have covered a great area in the interior of the continent, extending far to the north in the Mackenzie basin, and it appears probable that considerable portions of the western part of the Cordilleran region were also submerged, particularly to the north.

About the beginning of the Carboniferous period and thence onward the evidence becomes much more satisfactory and complete. In the earlier part of the Carboniferous, marine sediments, chiefly limestones, were laid down everywhere to the east of the Archean axis, while to the west of that axis (which was probably in large part itself submerged) ordinary clastic deposits, mingled with contemporaneous volcanic materials, were formed, tranquil epochs being marked by the intercalation of occasional limestone beds. It is not clearly apparent from what land the clastic materials were derived, but the area of vulcanism at this time was very great, covering the entire western part of British Columbia to the edge of the continental plateau and, as now known, extending northwest-

ward into Alaska and southward to California.

In the later time of the Carboniferous, however, the volcanic forces declined in their activity, and a great thickness of calcareous marine deposits occurred with little interruption of any kind. The area of land to the eastward was probably increased, for there is some evidence to show a first gentle uprising in the Laramide region at this time (or at least a cessation of subsidence), and no late Carboniferous strata have so far been found there.

No separate record for the Permian has yet been found in this part of the continent, but it must be remembered that, in view of the scanty character of the paleontological evidence, strict taxonomic boundaries can seldom be drawn. At about this time, however, very important changes occurred, for in the Triassic a great part of what is now the inland plain of the continent is found to have become the bed of a sea shut off from the main ocean, in which red rocks with salt and gypsum in some places were laid down. The northern part of this sea appears to have extended into the Canadian region for a short distance, covering the southern portion of the Laramide area. Farther north must have been the land boundary of this sea, and beyond this an extension of the Pacific ocean which swept entirely across the Cordillera. In the southern part of British Columbia, however, this ocean found its shore against the Gold ranges of the Archean axis, where the preceding Carboniferous beds had already been upturned and subjected to denudation. The Laramide region was not affected by volcanic action at this time, but vulcanism on a great scale was resumed in the entire western part of the Cordillera that had previously been similarly affected in the Carboniferous, and the ordinary marine sediments there form intercalations only in a great mass of volcanic products, probably in large part the result of submarine eruptions.

Such definite indications as exist of the Jurassic must, as already noted, be considered as physically attached to the Triassic of the interior plateau of British Columbia. It is probable that the greater part of the Jurassic period was characterized by renewed orogenic movements and by denudation, for when we are next able to form a connected idea of the physical conditions of the region these are found to have been profoundly modified.

It is to about this time that the elevation of the Sierra Nevada and some other mountain systems in the western states is attributed. In the region here particularly described, the Triassic and older rocks of the Vancouver range, or that forming Vancouver and the Queen Charlotte islands, were upturned, while a similar movement affected the zone now occupied by the British Columbia Coast ranges. These may not have been elevated into a continuous mountain system and barrier to the sea, but in any case the ranges then formed were, before the beginning of the Cretaceous period, largely broken down by denudation, so that the underlying granitic rocks supplied abundant arkose material to some of the lowest Cretaceous beds.

It is also probable that subsidence marked the close of the Jurassic, for in southern British Columbia the Pacific of the Earlier Cretaceous extended more or less continuously across the line of the Coast ranges, finding its shore not far to the east of this line. Farther north, although not without insular interruptions, it spread over the entire width of the Cordilleran belt, repeating the conditions found in the Triassic, but with the difference that it extended far to the south along the axis of the Laramide geosyncline, in which rapid subsidence had been renewed. In this early Cretaceous sea and along its margins and lagoons the

massive fossiliferous rocks of the Queen Charlotte islands and Kootanie formations were accumulated and coal beds were produced. Volcanic activity was renewed in some places, particularly near the present seaward margin of British Columbia. Sedimentation evidently proceeded more rapidly than subsidence in many localities and coal-producing forests, largely composed of cycadaceous plants, took possession of the newly formed lands from time to time.

The era of later Cretaceous appears, however, eventually to have been introduced by a marked general subsidence, which, as already noted, carried the Dakota sea entirely across the inland plain of the continent. The distribution and character of the ensuing Cretaceous formations show that the whole southern part of what is now the mainland of British Columbia soon after became and remained a land area, while the sea was more gradually excluded from the northern part of the Cordillera and continued to occupy the area of the Great plains and the present position of the Laramide range. Along the margin of the continental plateau, however, a renewed subsidence was in the main progressing southward and resulted ultimately in carrying the later Cretaceous sediments into the region of Puget sound.

The closing event of this cycle was the deposition of the Laramie beds on the east and in some places to the north, with probably the Puget group and its representatives on the coast, and this was followed by the most important and widespread orogenic movement of which we find evidence in the entire Rocky Mountain region. At this time the great Laramide range, or Rocky Mountain range proper, was produced, rising on the eastern side of the Archean axis along a zone that had previously been characterized from the dawn of the Paleozoic by almost uninterrupted subsidence and sedimentation. That the pressure causing this upthrust of the Laramide range was from the westward is clearly shown by the great overthrust faults in this range. The stability of the old Archean axis, which it may be supposed had previously sustained the tangential thrust from the Pacific basin must at this time have been at last overcome. As a part of the result of this, the chief belt of faulted strata in the Laramide range, originally about 50 miles wide, became reduced in width by one-half. How rapidly this great revolution may have occurred we do not know, but it probably did not occupy a long time from a geological point of view, and the Laramide range, as first produced, may very possibly have attained a height approaching 20,000 feet.* The thickness of stratified rocks in the geosyncline was at the time probably more than 40,000 feet.

It is difficult to determine to what extent the Archean axis with the Gold ranges and other preexisting mountains was affected at this period of orogenic movement, because of the absence of the newer formations there, but it seems probable that no very important change took place. Farther west, however, the great zone of Coast ranges was elevated, and the corrugated and vertical Cretaceous beds, met with even on their inland side, show that large parts of the Interior plateau of British Columbia and of the country in line with it to the northward were flexed and broken. Similar conditions are found to have affected Cretaceous rocks of Vancouver and the Queen Charlotte islands, of which the

* This refers particularly to the better known region near the Bow pass. See Annual Report, Geol. Surv. Can. (N. S.) Vol. II., p. 31 D, and *Am. Jour. Sci.*, Vol. XLIX., p. 463. The base of the mountains may at this time have been nearly at sea level, or 4,000 feet lower than at present, while the actual height at any time attained would depend upon the rapidity of uplift relative to denudation. The total height of folded strata is estimated at from 32,000 to 35,000 feet.

mountain axis, previously in existence, was evidently greatly increased in elevation.

The Laramide geosyncline has already been particularly referred to and allusion has been made to the now well recognized fact that by such zones of continued subsidence and deposition the lines of most mountain systems have been determined. To the Laramide geosyncline here, the mountains of the Archean axis—the Gold ranges—stood in much the same relation as the Archean western border of the Wasatch to the Laramide geosyncline in Utah (as described by Dana), but on a larger scale.

On the other or western side of this axis, as already noted, I am now led to regard the zone of country extending to the Vancouver range as a second and wider geosyncline with a breadth of about 200 miles, in which a thickness of deposits, perhaps greater than that of the Laramide, but in the main composed of volcanic ejectamenta, had by this time been accumulated. The volume of the Carboniferous and Triassic rocks alone must have exceeded 20,000 feet. It is probable that to this may be added a great thickness of older rocks,* for the circumstance that volcanic action was so persistent here and the amount of extravasation resulting from it was so enormous, implies a recognition of the fact that, along this zone (not far from the edge of the continental plateau) the isogeotherms, with what we may call the plane of granitic fusion, had crept up to a position abnormally near the surface. It is to this probably that we may attribute the apparent absence of Archean rocks in the Coast ranges, or at least the impossibility of defining any rocks of that period there, for these, together, no doubt, with great volumes of later deposits, may be assumed to have become merged in the rising granitic magma, on which strata of Triassic age are now often found lying directly, arrested in the very process of absorption.*

When the Laramide revolution occurred, by reason of the increasing tangential pressure from the Pacific basin and the growing failure of resistance of the two great geosynclines of this part of the Cordillera, the Laramide range was produced by the folding and fracture of a very thick mass of beds, of which the crystalline base has not yet been revealed by denudation, while in the western trough an eversion of the axis of settlement seems to have occurred, resulting in the appearance of a granitic bathylite of nearly a thousand miles in length, from which the comparatively thin covering of unabsorbed beds was soon afterward almost completely stripped away by ensuing processes of waste.

This last great epoch of mountain making doubtless left the surface of the Cordilleran belt generally with a very strong and newly made relief, which before the middle of the Tertiary period is found to have become greatly modified by denudation. Chiefly because no deposits referable to the Eocene or earliest Tertiary have been found in this part of the Cordillera, it is assumed with probability that this was a time of denudation. It is further indicated that it was a time of stability in elevation by the fact that the prolonged wearing down resulted, in the interior zone of the Cordillera, in the production of a great peneplain, the base-level of which shows that the area affected stood for a very long time 2,000 or 3,000 feet lower in relation to the sea than it now does. If, however, the Puget beds of the coast are correctly referred to the Eocene, it follows that the coast region was at the same period

*Several thousand feet of Cretaceous rocks must also be added to this thickness near the line of the present Coast ranges, and the total thickness of deposits in the center of this geosyncline must probably have exceeded 40,000 feet.

*Annual Report, Geol. Surv. Can., Vol. II. (N. S.), 1886, p. 11 B et seq.

only slightly lower than at present, and that the movements in subsidence and elevation between this and the interior region must have been differential in character and very unequal in amount.

As already noted, the earliest Tertiary sediments of the Interior plateau of the Cordillera are referred to the Oligocene. Probably some further subsidence at that time interrupted the long preceding time of waste. This period of deposition was in turn closed by renewed disturbance of an orogenic kind, comparatively slight in amount and local, chiefly affecting certain lines in a northwest and southeast direction. Next came renewed denudation or 'planation,' and this continued until the enormous volcanic extravasations of the Miocene began.

It is not proposed in this place to recapitulate in detail the physical conditions of the Tertiary period, for it has already been necessary to refer to these in connection with the description of the beds themselves, which, because they have not been materially changed since their deposition, really tell their own tale.

It need only be said that, after the Oligocene lake deposits had been formed, disturbed and denuded, new series of lakes were from time to time produced at different stages during the Miocene, their beds now generally appearing as intercalations in volcanic deposits of great mass. Both the coast and the interior region appear to have been subject to these conditions, while the Laramide range stood high, with the inland plain of the continent sloping eastward from its base.

Following the close of, or at least a great reduction in, volcanic activity in the early Pliocene, the interior zone of the Cordillera again assumed a condition of stability for a considerable time, during which wide and 'mature' stream valleys were formed. The elevation of the interior plateau region of British Columbia must then have been about 2,000 feet less than it is at present.* Farther north, the yellow Pliocene gravels of Horsefly river and other places are attributed to this period, and the southern aspect of their contained fossil plants is such as to indicate that, in the given latitude, the height of that part of the interior can not have been much above the sea level.

In the later Pliocence a very marked reelevation of the Cordilleran region evidently occurred, leading to the renewed activity of river erosion, the cutting out of deep valleys and canyons, and the shaping of the surface to a form much like that held by it at the present day. This elevation in all probability affected the coast as well as the interior, and it would appear that the rivers for a time extended their courses to the edge of the continental plateau.

The excavation of the remarkable fiords of British Columbia and the southern part of Alaska must, I think, be chiefly attributed to the later portion of the Pliocene, although it is quite possible that the cutting out of the valleys may have been begun soon after the Laramide upheaval. The antiquity of these valleys is evidenced by the fact that several comparatively small rivers still flow completely across the Coast ranges in their deep troughs. The fiords are now essentially the submerged lower parts of these and other drainage valleys of the old land, not very materially affected by the later glacial action, important as this has undoubtedly been from other points of view. The valleys of the fiord-like lakes that occur along the flanks of the Archean axis of the interior may probably also be referred to river erosion in the later Pliocene, but if so this mountain region must have been affected by a relatively greater uplift at that time, followed later by a subsidence of its central part. It appears,

* *Trans. Royal Soc. Can.*, Vol. VIII., Sec. IV., p. 18.

however, that the excavation of valleys or gorges like these by rivers, when the slope and water supply are favorable, occurs with such rapidity relative to the wider effects of denudation, as to be almost negligible in any general view of the physical changes of an extensive region or in the accounting of geological time.

There is as yet some difficulty in connecting the later physical changes particularly referred to above with those which have recently come under observation far to the north in the Klondike region. It is probable, however, that the auriferous 'quartz drift' of that region, implying long subaërial decay and stability of level, may be attributed to the early Pliocene; while the river gravels found in the newer and deeper-cut valleys may be assigned to the later Pliocene time of greater elevation. During the Pliocene, and probably until its close, the mammoth, one or two species of bison, the moose and other large mammals roamed northward to the Arctic sea. Then came the Glacial period, with renewed great changes in levels and climate and its own peculiar records and history, which in many respects are more difficult of interpretation than those of more remote periods, because the whole time occupied by them has been relatively so brief. I have elsewhere endeavored to follow this history in detail, and do not propose on this occasion to deal with this latest chapter of the physical history of the Rocky Mountain region of Canada.

In conclusion, what appear to be the most striking points evidenced by the geological record of this northern part of the Cordillera may perhaps be specified as follows:

1. The great thickness of strata accumulated both to the east and west of an Archean axis. In the Laramide geosyncline the strata no doubt actually attained the volume stated. In the western and wider syncline it is not so certain that all the formations in their full thickness were ever actually superposed at any one place or time (for reasons already alluded to), but the volume was probably not less than in the Laramide region.

2. The great proportion of volcanic materials accumulated in the western geosyncline and the recurrence of vulcanism throughout the geological time-scale in this region, resulting in the production of massive volcanic formations in the Cambrian, Carboniferous, Triassic, Cretaceous and Miocene.

3. The recurrence of folding and disturbance parallel to the border of the Pacific basin and the concurrent great changes in elevation of the land relatively to the sea, both continued down to quite recent geological times, the latter even into the Pleistocene.

4. The tremendous energy of denudation, in part due to the events last referred to, but also dependent upon the position of the region on the eastern border of a great ocean, where, in northern latitudes, an excessive rainfall must have occurred at all periods on the seaward mountain ranges. No comparable denuding forces were probably ever operative on the east side of the continent in similar latitudes since the definition of the ocean basins of the Pacific and Atlantic.

G. M. DAWSON.
GEOLOGICAL SURVEY OF CANADA.

STEREOSCOPIC STUDY OF THE MOON.

IN looking at a terrestrial landscape we see that certain features are distant and others near. We also recognize the extension of objects in three dimensions, so that a tree, for example, is not a mere silhouette, but is perceived in its proper rotundity. The data for these automatic and instantaneous judgments as to distance and form are somewhat complex. The distance of